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Statistical analysis of low-flows in Wallonia

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AMICE *Adaptation of the Meuse to the Impacts of Climate Evolutions* is an INTERREG IVB North West Europe Project (number 074C).
Climate change impacts the Meuse basin creating more floods and more droughts. The river managers and water experts from 4 countries of the basin join forces in this EU-funded transnational project to elaborate an innovative and sustainable adaptation strategy. The project runs lasts from 2009 through 2012.
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Introduction

Context

Climate change and its impacts on the water resources management appear in the European Union's priorities: Green Paper on climate change, Communication on Water Scarcity and Droughts, Floods Directive (2007/60/EC),…

The floods have always been the main concern resulting of extreme weather conditions. Now droughts and low flows are more and more recognized as risk situations due to the huge consequences of water shortage. Furthermore, the changing climate context constitutes a new threat even if the uncertainty in low-flows evolution remains high.

A work must consequently be executed on the low-flow occurrence probability. In Wallonia, a knowledge gap remains on statistical analysis of low-flows. The University of Liège, Gembloux Agro-Bio Tech had for goal to compensate the lack of knowledge on statistical low-flow data in Wallonia.

Low-flow indicators

Two indicators that characterize low-flow in a different manner are chosen for this study: Q95 and MAM7. These indicators are less sensitive to the measurement errors than the minimum discharge.

The MAM7 represents the annual minimum of the mean on 7 consecutive days of daily flows. It is used in the Netherlands, in Germany and also in the United-States and United Kingdom. It was chosen by the partners within the framework of the AMICE project (WP1 AC3).

The percentile 95 is the flow that is exceeded 95% of the time. This indicator is largely spread in Europe for his pertinence in numerous fields of water resources management. (Smakhtin, 2001)

Hydrological data

A main problem in Wallonia is the short history in the hydrological monitoring. (Figure 1) The first monitoring site was installed in 1960. It consisted in a limnimetric scale and daily manual readings. Since 1974, hourly data are recorded. The number of measurement sites reached 244 stations in 2011.

A qualitative analysis of monitoring stations led us to disregard 184 stations. The main quality problems were short recording periods, important extrapolation of the discharge rating curve, algae development in summer, low flow below 5 l/s, flows derived from next stations. In order to try to get back a few monitoring sites or data years, three analyses were performed.

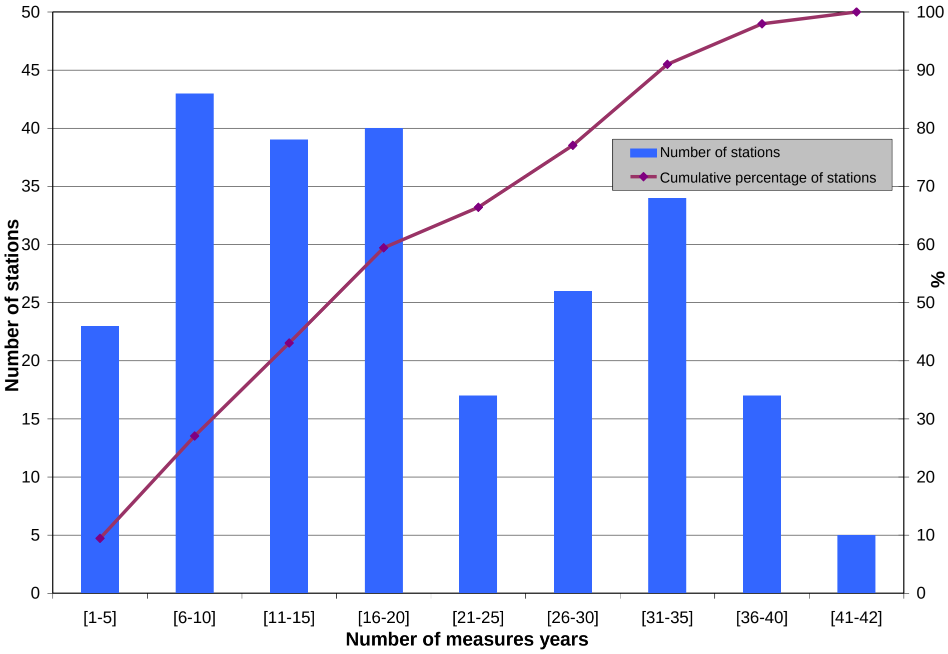

Figure 1 : Number of stations in function of the historic size.

- Firstly, the ***old manual daily readings*** were analyzed. In the past, the water height data were daily read at a set time (8h am) by an operator. Unusable in high flow situations, they still hold practical and usable information during drought. The variability during a day in period of low flows is indeed weak. These data are validated from sites with 25 years of data. A test for the equality of means was done to compare the means of percentile 95 obtained from the daily data and the means of percentile 95 from hourly data at 8 am (Dagnélie, 1975). These last data are equivalent to the water height read by the operator. The analysis allows us *to extend the registration period of 7 stations and to recover 16 stations*.

- Secondly, a ***lot of data*** are ***missing during the 1960-1994 period***, due to a poor management of the monitoring network. A yearly hydrograph analysis led us to keep years of partial measurement when the gaps were found to be out of the low-flow period. The treatment permits to *increase the historic of 51 stations*. A few monitoring sites have gained up to 10 years of data.

- Thirdly, in Wallonia, about 60 % of the monitoring sites have less than 20 years of hourly data (see Figure 1) which is the historic duration recommended in the literature for the low-flows' characterization (Laaha, 2005). A methodology based on the mean and standard deviation of indicators Q95 and MAM7 is applied on monitoring sites situated in different catchment areas in the Walloon region and with at least 20 years of data. For each site, the number of recording years necessary for the ***minimal historic*** is calculated in such a way that the relative deviation between the sample mean and the general mean as well as the relative deviation between the sample variance and the general variance are both inferior to a defined tolerance (10%). The results are similar for the two indicators; the minimum historic size issued of this method is about 20 years. *No site with a short historic can be recuperated*.

After the measuring sites' selection for the frequency analysis, a homogeneity test is performed on the data. The goal of this test is to verify if all the low flows of a station are issued of one population in a statistical sense. The most frequent heterogeneities' causes are: the displacement of a measuring site, the change in the discharge rating curve, the change in the catchment area management. The test consists in a test for the equality of means (Student test). The samples are considered to have the same variance. The total population is represented by the n percentiles 95 or n MAM7 calculated for all the years of each site.

Three homogeneity tests are realized depending on the division of the population. The population is cut into two samples of the same size; at the level of the year 1992 (change in the management team) and at the transition between limnimetric scales and limnigraphics recordings.

↳ Finally ***64*** out of 244 monitoring sites are kept for the frequency analysis.

Frequency analysis

The frequency analysis consists in the adjustment of a statistical law to the hydrological observations for each station. The objective is to calculate the critical low flow Q_T that corresponds to a given return period T. T is defined as the mean time between two occurrences of low flows. To do so, we used probabilistic models. These models are mathematical formulations that aim at simulate natural hydrological phenomenon such as probabilistic processes based on the probabilistic analysis of the considered random variables (in this study, Q95 and MAM7).

The laws currently used in hydrology are the following: Normal, Log-normal, Gumbel, Generalized Extreme Value, Weibull, Gamma, and Pearson. After having chosen the law, the parameters must be estimated by the method of moments, the method of maximum likelihood or even the L-moments method and probability-weighted moments. (Ashkar & Mahdi, 2006; Condie & Nix, 1975; Galea & *al.*, 1999; Greenwood & *al.*, 1979; Gumbel, 1954; Hosking & *al.*, 1985; Hosking, 1986; Joseph, 1970; Landwher, 1979; Leppajarvi, 1989; Matalas, 1963; Nathan, 1990; Tasker, 1987) A test of adequacy (the exam of skewness coefficient and kurtosis coefficient, the khi² test, the Kolmogorov-Smirnov test or the Cramer-Smirnov-Von mises test) is then performed in order to verify the good harmony between observations and the corresponding probability laws (Joseph, 1970; Prakash, 1981; Shao & *al.*, 2008). Several distributions can supply adjustments statistically acceptable but this test doesn't permit to draw conclusions on the choice of the best law. To determine the law that fits the best to the data, the graphical method stays the most efficient tool.

Adjustment methodology

Five distributions often used for the low-flow discharges analysis are tested with the HYFRAN software: Weibull (2 parameters), log-normal 2 parameters (LN2) and 3 parameters (LN3), Gamma and Pearson type III. Furthermore, the Fréchet law is also tested. The parameters of the laws are estimated by the maximum likelihood estimation (MLE). The selection of the three best laws is performed for each site thanks to three Bayesian criterions proposed by HYFRAN. These three criterions are used to select the most likely model in view of data. They permit to build a classification of statistical models taking into account the parsimony principle that favors the 2 parameters laws. The khi² test is applied to verify the adequacy of these distributions to the sample of observed values. To be selected, the null hypothesis must be accepted for the distribution.

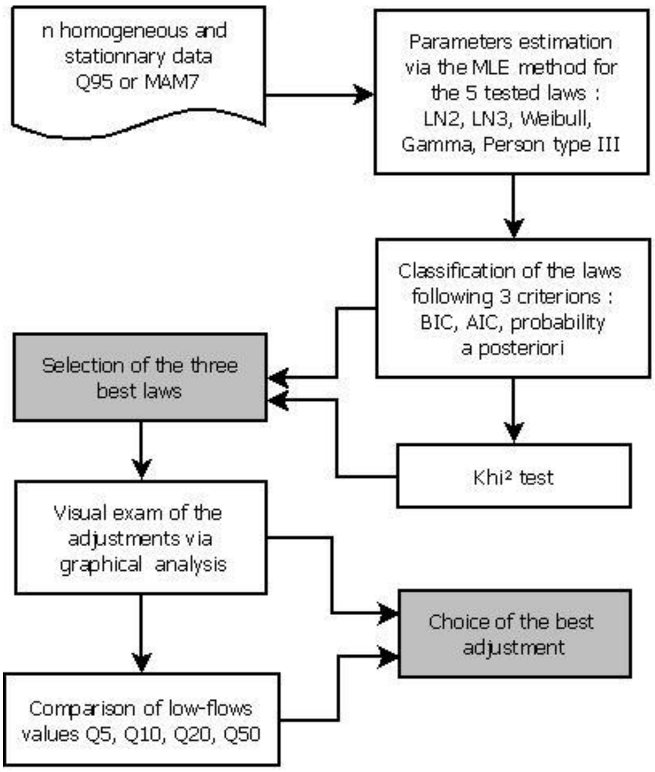

Figure 2 : Diagram of the methodology used in the choice of the best adjustment for each station

Finally the distribution that fits the best to the data is visually chosen. The incertitude associated to the choice of the law is considered for the estimation of the quantiles. Indeed the theoretical occurrence probabilities of studied events are unknown and we search a probability law that gives a good approximation. That is why, for each adjustment, the quantiles of return period are estimated with a confidence interval of 95%.

Results

The results of the adjustment method are similar for the two indicators. The Gamma and the log-normal distributions are the most used. For the indicator Q95, the lognormal is more appropriated followed closely by the Gamma while it is the contrary for the MAM7. In some cases a three parameters law fits best to the data. The Weibull law proves to be unadapted for the low flow discharge in Wallonia.

The tables below (Table 1and Table 2) resume the best adjustment for all the monitoring sites. We calculated also values of low-flows for different return periods: 5, 10, 20 and 50 years. Fifty years is the maximal period in view of the number of working years of the gauging sites.

Table 1 : Best adjustment and discharge values for Q95 law flow indicator.

Station	Law Q95	Q T=5ans [m³/s]	Q T=10an [m³/s]	Q T=20ans [m³/s]	Q T=50ans [m³/s]
Martinrive_Amblève	Pearson type III	2.870	2.540	2.340	2.170
Trois-pont_Salm	Lognormale	0.535	0.457	0.402	0.348
Lorcé_Lienne	Lognormale	0.278	0.225	0.189	0.156
Harnoncourt_Ton	Gamma	2.020	1.820	1.660	1.490
Ruette_Vire	Lognormale	0.209	0.179	0.157	0.136
Athus_Messancy	Gamma	0.130	0.107	0.090	0.073
Latour_Vire	Lognormale	0.255	0.216	0.188	0.161
Irchonwelz_Dendre-occi	Lognormale	0.120	0.104	0.093	0.082
Ath_Dendre-ori	Gamma	0.281	0.226	0.187	0.149
Isières_Sille	Gamma	0.023	0.017	0.013	0.010
Brugelette_Dendre-ori	LogNormale 3 param.	0.184	0.138	0.101	0.059
Bierges_Dyle	Gamma	1.240	1.150	1.070	0.986
Suzeril_Thyle	Gamma	0.235	0.199	0.172	0.145
Amougies_Rhosnes	Gamma	0.124	0.095	0.075	0.056
Bergilers_Geer	Pearson type III	0.312	0.284	0.268	0.256
Kanne_Geer	Gamma	1.350	1.210	1.100	0.989
Opheylissem_PetiteGette	Lognormale	0.466	0.413	0.373	0.333
Hoegaarden_GrandeGette	Gamma	0.565	0.513	0.473	0.430
Haine_Boussoit	Pearson type III	0.542	0.474	0.427	0.382
Baisieux_GrandeHonnelle	Fréchet	0.226	0.218	0.214	0.211
Hastière_Hermeton	Fréchet	0.182	0.169	0.162	0.157
Modave_Hoyoux	Pearson type III	0.366	0.336	0.319	0.306
Daverdisse_Lesse	Lognormale	0.514	0.424	0.361	0.302
Resteigne_Lesse	Lognormale	0.517	0.417	0.349	0.286
Ochamps_Lesse	Lognormale	0.020	0.016	0.013	0.010
Graide_RuisseaudeGraide	Gamma	0.012	0.008	0.005	0.003
Our_Eaud'Our	Fréchet	0.107	0.081	0.064	0.051
Lavaux_Wimbe	Lognormale	0.054	0.038	0.029	0.021
Grupont_Lhomme	Gamma	0.272	0.180	0.124	0.078
Eprave_Lhomme	Lognormale	0.810	0.674	0.578	0.487
Moha_Mehaigne	Gamma	0.672	0.569	0.493	0.416
Wanze_Mehaigne	Fréchet	0.725	0.650	0.600	0.559
Upigny_Mehaigne	Pearson type III	0.017	0.012	0.009	0.005
Ambresin_Mehaigne	Gamma	0.304	0.244	0.202	0.161
Felenne_Houille	Lognormale	0.170	0.138	0.117	0.096
Warnant_Molignee	Gamma	0.506	0.456	0.417	0.376
Rhisnes_Houyoux	Lognormale	0.025	0.020	0.016	0.013
Gedinne_Houille	Gamma	0.079	0.057	0.043	0.030
Dalhem_Berwinne	Gamma	0.221	0.170	0.134	0.101
Nisramont_Ourthe	Fréchet	0.930	0.787	0.708	0.655
Sauheid_Ourthe	LogNormale 3 param.	6.426	5.829	5.452	5.122
Hamoir_Néblon	Gamma	0.143	0.116	0.097	0.078
Erneuville_Ourthe	Gamma	0.316	0.223	0.163	0.111

Baillonville_ruisseauHeure	Lognormale	0.039	0.031	0.026	0.021
Cerfontaine_EauHeure	Pearson type III	0.032	0.030	0.029	0.028
Wihéries_Hantes	Lognormale	0.196	0.167	0.146	0.126
Bersillies_Thure	Pearson type III	0.111	0.101	0.095	0.090
Aiseau_Biesme	Lognormale	0.169	0.145	0.127	0.110
Walcourt_Ryd'Yves	Fréchet	0.130	0.092	0.064	0.038
ThyLeChateau_Thyria	Gamma	0.104	0.088	0.076	0.064
Membre_Semois	Gamma	2.025	1.568	1.251	0.954
SteMarie_Semois	Gamma	0.307	0.254	0.216	0.179
Tintigny_Semois	Gamma	0.579	0.463	0.380	0.301
Straimont_Vierre	Lognormale	0.243	0.189	0.153	0.121
Tintigny_Rulles	Gamma	0.205	0.142	0.102	0.067
Marbehan_Mellier	Gamma	0.055	0.034	0.021	0.012
Ronquières_Samme	Gamma	0.359	0.328	0.304	0.278
Tubize_Senne	Weibull (MM)	0.306	0.259	0.221	0.181
Martelange_Sure	Lognormale	0.160	0.111	0.081	0.058
Brouffe_Mariembourg	Lognormale	0.015	0.011	0.008	0.006
Nismes_EauBlanche	Lognormale	0.230	0.195	0.170	0.146
Couvin_EauNoire	Lognormale	0.205	0.168	0.142	0.118
Treignes_Viroin	Lognormale	0.655	0.554	0.483	0.413
Bruly_RydePernelle	Lognormale	0.075	0.063	0.055	0.047

Table 2 : best adjustment and discharge values for the MAM7 low flow indicator.

Station	Loi MAM7	Q T=5ans [m³/s]	Q T=10ans [m³/s]	Q T=20ans [m³/s]	Q T=50ans [m³/s]
Martinrive_Amblève	Lognormale 3 param.	2.630	2.350	2.170	2.000
Trois-pont_Salm	Lognormale 3 param.	0.464	0.412	0.378	0.348
Lorcé_Lienne	Lognormale	0.224	0.181	0.151	0.124
Harnoncourt_Ton	Gamma	1.900	1.690	1.530	1.360
Ruette_Vire	Gamma	0.194	0.163	0.140	0.118
Athus_Messancy	Gamma	0.106	0.083	0.066	0.051
Latour_Vire	Gamma	0.218	0.176	0.146	0.117
Irchonwelz_Dendre-occi	Lognormale	0.110	0.095	0.085	0.074
Ath_Dendre-ori	Pearson type III	0.254	0.195	0.149	0.101
Isières_Sille	Gamma	0.017	0.013	0.010	0.007
Brugelette_Dendre-ori	Lognormale 3 param.	0.163	0.121	0.086	0.047
Bierges_Dyle	Gamma	1.190	1.090	1.020	0.939
Suzeril_Thyle	Gamma	0.221	0.188	0.163	0.139
Amougies_Rhosnes	Gamma	0.101	0.075	0.058	0.043
Bergilers_Geer	Lognormale	0.305	0.263	0.233	0.203
Kanne_Geer	Gamma	1.300	1.160	1.060	0.947
Opheylissem_PetiteGette	Lognormale	0.461	0.410	0.372	0.334
Hoegaarden_GrandeGette	Gamma	0.518	0.466	0.426	0.384
Haine_Boussoit	Gamma	0.517	0.441	0.385	0.328
Baisieux_GrandeHonnelle	Lognormale	0.221	0.205	0.193	0.180
Hastière_Hermeton	Pearson type III	0.171	0.153	0.143	0.135

Modave_Hoyoux	Lognormale	0.359	0.319	0.289	0.259
Daverdisse_Lesse	Lognormale	0.428	0.346	0.291	0.239
Resteigne_Lesse	Lognormale	0.426	0.340	0.282	0.229
Ochamps_Lesse	Gamma	0.017	0.013	0.010	0.007
Graide_RuisseaudeGraide	Gamma	0.007	0.004	0.002	0.001
Our_Eaud'Our	Lognormale	0.117	0.095	0.080	0.066
Lavaux_Wimbe	Lognormale	0.040	0.027	0.019	0.013
Grupont_Lhomme	Gamma	0.217	0.139	0.093	0.055
Eprave_Lhomme	Lognormale	0.698	0.585	0.506	0.430
Moha_Mehaigne	Fréchet	0.595	0.528	0.483	0.447
Wanze_Mehaigne	Fréchet	0.673	0.605	0.561	0.525
Upigny_Mehaigne	Pearson type III	0.014	0.009	0.006	0.002
Ambresin_Mehaigne	Gamma	0.266	0.213	0.175	0.139
Felenne_Houille	Lognormale	0.145	0.118	0.099	0.082
Warnant_Molignee	Gamma	0.484	0.436	0.399	0.361
Rhisnes_Houyoux	Gamma	0.022	0.016	0.012	0.009
Gedinne_Houille	Fréchet	0.068	0.045	0.027	0.009
Dalhem_Berwinne	Lognormale 3 param.	0.196	0.139	0.096	0.052
Nisramont_Ourthe	Lognormale	0.761	0.588	0.475	0.373
Sauheid_Ourthe	Lognormale 3 param.	5.300	4.700	4.310	3.970
Hamoir_Néblon	Gamma	0.128	0.103	0.085	0.068
Erneuville_Ourthe	Gamma	0.273	0.192	0.140	0.095
Baillonville_ruisseauHeure	Gamma	0.030	0.023	0.018	0.013
Cerfontaine_EauHeure	Lognormale	0.030	0.027	0.025	0.023
Wihéries_Hantes	Lognormale	0.174	0.149	0.131	0.113
Bersillies_Thure	Lognormale	0.105	0.094	0.087	0.079
Aiseau_Biesme	Gamma	0.150	0.125	0.107	0.089
Walcourt_Ryd'Yves	Lognormale 3 param.	0.120	0.087	0.063	0.040
ThyLeChateau_Thyria	Fréchet	0.090	0.069	0.050	0.028
Membre_Semois	Lognormale	1.630	1.300	1.080	0.877
SteMarie_Semois	Gamma	0.230	0.180	0.146	0.113
Tintigny_Semois	Fréchet	0.429	0.315	0.229	0.148
Straimont_Vierre	Gamma	0.164	0.111	0.078	0.049
Tintigny_Rulles	Lognormale	0.152	0.111	0.086	0.065
Marbehan_Mellier	Lognormale	0.034	0.022	0.016	0.010
Ronquières_Samme	Gamma	0.314	0.283	0.259	0.235
Tubize_Senne	Weibull (MM)	0.278	0.234	0.199	0.161
Martelange_Sure	Lognormale	0.127	0.087	0.063	0.044
Brouffe_Mariembourg	Lognormale	0.011	0.008	0.007	0.005
Nismes_EauBlanche	Gamma	0.190	0.152	0.125	0.099
Couvin_EauNoire	Gamma	0.168	0.132	0.106	0.083
Treignes_Viroin	Gamma	0.557	0.453	0.378	0.305
Bruly_RydePernelle	Lognormale	0.062	0.051	0.044	0.037

Conclusion

Wallonia has a quite young monitoring network for river discharge. In this context, a statistical analysis requires cautiousness. The present report showed that only 64 out of 244 stations are sufficiently robust to provide good data for such an analysis.

This situation will improve gradually during the coming years until the whole network reaches its maturity. Nevertheless, the present report shows a complete methodology of low-flows statistical analysis and the results of the 64 stations. Regarding the stations' pyramid of ages, this analysis would be usefully updated after 5 years.

The next step is the regionalization of the low flows in Wallonia. The goal will be to identify groups of catchment areas that have a similar hydrological behaviour. The delimitation of regions will be realised on the basis of physiographic considerations (slope, catchment zone area, precipitation,…) and on the basis of the hydrological response of the catchment zone (characteristic flow, statistical value,…).

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